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GEORGE C. MARSHALL SPACE FLIGHT CENTER
HUNTSVILLE, ALABAMA

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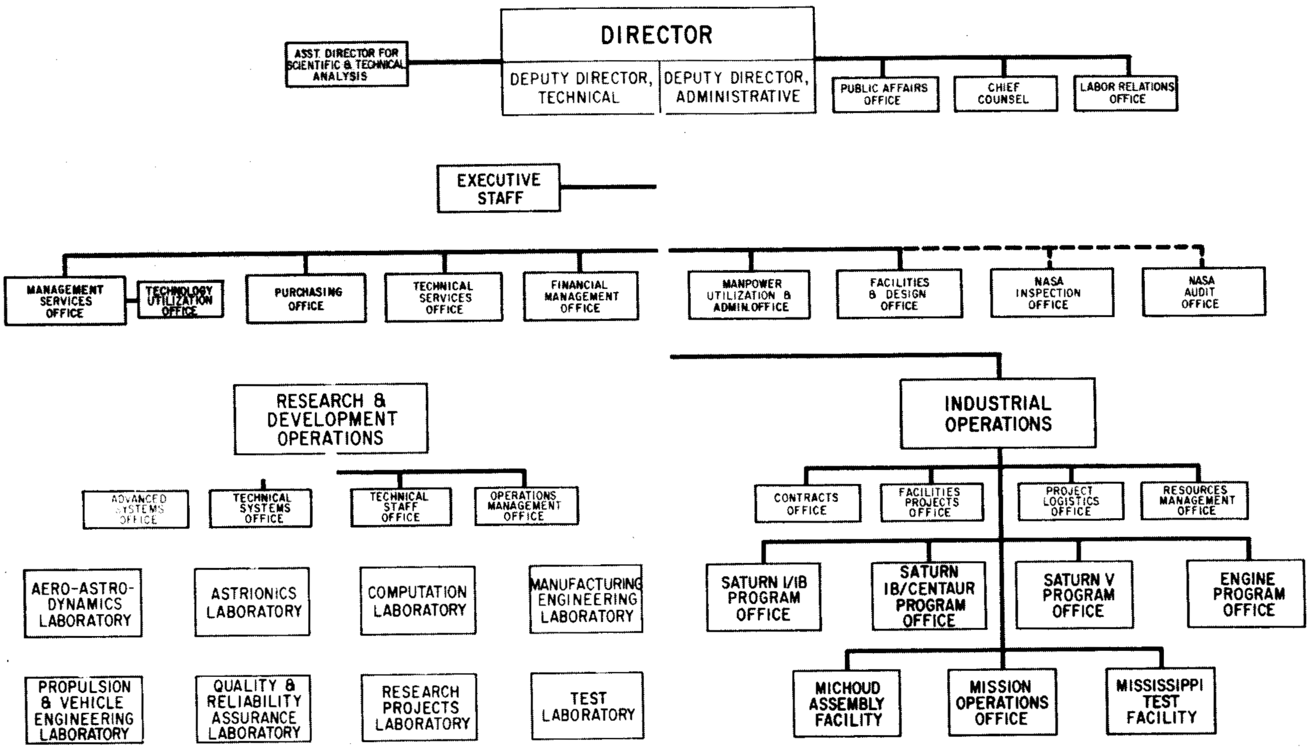

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D. C.

QUALITY ASSURANCE AND CHECKOUT RESEARCH AT MSFC

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PREFACE

In 1955, the team which has become the Marshall Space Flight Center (MSFC) began to organize a research program within its various laboratories and offices. The purpose of the program was two-fold: first, to support existing development projects by research studies and second, to prepare future development projects by advancing the state of the art of rockets and space flight. Funding for this program came from the Army, Air Force, and Advanced Research Projects Agency. The effort during the first year was modest and involved relatively few tasks. The communication of results was, therefore, comparatively easy.

Today, more than ten years later, the two-fold purpose of MSFC's research program remains unchanged, although funding now comes from NASA Program Offices. The present yearly effort represents major amounts of money and hundreds of tasks. The greater portion of the money goes to industry and universities for research contracts. However, a substantial research effort is conducted in house at the Marshall Center by all of the laboratories. The communication of the results from this impressive research program has become a serious problem by virtue of its very voluminous technical and scientific content.

The Research Projects Laboratory, which is the group responsible for management of the consolidated research program for the Center, initiated a plan to give better visibility to the achievements of research at Marshall in a form that would be more readily usable by specialists, by systems engineers, and by NASA Program Offices for management purposes.

This plan has taken the form of frequent Research Achievements Reviews, with each review covering one or two fields of research. These verbal reviews are documented in the Research Achievements Review Series.

Ernst Stuhlinger
Director, Research Projects Laboratory

These papers presented June 24, 1965

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IMPROVEMENTS IN STAGE CHECKOUT

By

R. L. Smith, Jr.

SUMMARY

Improvements in the checkout of space vehicle stages are discussed in this report under four categories of work: a guideline document for analysis and checkout of space vehicle stages, improvements in automated checkout, checkout display requirements, and single parameter testing.

The guideline document, now used by NASA and supporting contractors, explains the rationale for all checkout requirements and provides general and specific checkout instructions.

Improvements in automated checkout have been obtained through the development of a digital event evaluator, a computer method for instrument calibration, and control methods for stage checkout. These improvements provide for simplified, more accurate data acquisition, for automatic readout, and for computer programing of the calibration of inflight instrumentation. More work is needed on the refinement of computer-control operations that require manual intervention.

Work is continuing on checkout display requirements which deal with information presentations on real-time running status, troubleshooting, and assistance in test procedure generation. Some of the developments include the use of cathode-ray screens for displaying a matrix of variables, complex flow diagrams, and information stored in digital form.

In single parameter testing, a single signal (sine or complex wave, step function, exponential function, etc.) is the input to a device being tested, and the output signal is observed for both normal and deviate response. Current work is concerned with finding the appropriate combination of input and output signals for the precise computer identification of normal and faulty operation of various devices or systems.

I. INTRODUCTION

One of the major responsibilities of Quality and Reliability Assurance Laboratory is the checkout of vehicle stages after the completion of manufacturing assembly and static firing. Since many problems are encountered in this complex of operations, solutions have to be sought through studies and engineering developmental work. These are financed mainly through supporting research funds, although in some cases this support is not requested.

This report covers the following achievements in stage checkout improvement: a guidline document on stage analysis and checkout, automated checkout, checkout display requirements, and single parameter testing. The guideline document was written mainly in house, but some contract assistance was used (General Electric Corp., contract NASw-410). The other work, with the one exception, was supported entirely with research funds. The exception was the Digital Event Evaluator (for automated checkout). Its initial work used supporting research funds, but after its feasibility was established, it was completed under line-program funding.

II. GUIDELINE DOCUMENT FOR ANALYSIS AND CHECKOUT OF SPACE VEHICLE STAGES

Over the past ten years, MSFC has developed a pattern of operation in stage checkout which takes into account many variables, some of which are time available; safety considerations; engineering modifications in stage and checkout equipment, made during checkout; and extent of detail to which checkout is needed. This pattern has been reexamined a number of times with a view toward optimizing the process within these variables, and toward maintaining the general philosophy of conservative development, which has been a leading factor in the high degree of success for MSFC programs.

Stated generally, the objective of checkout is to establish that the vehicle stage complies with the following requirements: (1) it is built according to design documentation, (2) it functions according to design intent, (3) it will mate properly with the other vehicle stages, and (4) it will mate properly with the launch site ground equipment.

Satisfying the requirements of one checkout objective does not necessarily guarantee compliance by another. This has been demonstrated many times. An example is given by Jupiter AM 2 testing: when umbilicals were disconnected for simulation of lift-off during the simulated flight test, the missile became completely inoperative. It has been demonstrated a number of times, too, that when an item functions properly on the bench, this does not necessarily mean that it will function properly in the stage. It is safe to say that after testing in a complete checkout has been successfully completed, it is established only that the stage will perform properly at that point in time. Based on experience, stage performance may be predicted for future operations, provided that the tests are properly designed and the existing local limitations are recognized (e.g., a simulated flight test).

Problems with satisfying the general objectives of checkout were encountered as soon as MSFC began working with stage (and missile) contractors who were doing the building and checking out. The basic problem was that the contractors did not appear to have the same concern for care in all aspects as did MSFC. Therefore, MSFC requirements were set down not only to establish specific guidelines but to show the basic rationale for them.

Guidelines for the following areas of checkout were included in the document: (1) receiving inspection, (2) fabrication analysis, (3) analysis of components and minor subassemblies, (4) analysis of major subassemblies, (5) stage analysis, and (6) checkout of assembled stages. The document is intended to provide guidance that is sufficiently general to be applicable to any stage, yet sufficiently specific to ensure detailed coverage in technique and supporting rationale. For example, specific guidelines deal with planning, data coverage required, reporting, recordkeeping, and examples of operations on typical items of a stage.

III. IMPROVEMENTS IN AUTOMATED CHECKOUT

An evaluator of digital data, a computer method of instrument calibration, and advances in control methods for stage checkout constitute important achievements in the program to improve automated checkout. The results of these achievements have been or will be applied.

A. DIGITAL EVENT EVALUATOR

For many years Esterline-Angus (EA) drag pen recorders (Fig. 1) were used in checkout operations

FIGURE 1. ESTERLINE-ANGUS DRAG PEN RECORDERS AND DIGITAL EVENT EVALUATOR

to provide a chronological record of occurrence of discrete events characterized by a step change in voltage between 0 and 28 volts. Each recorder chart contains 19 information channels and a time-pulse channel (Fig. 2). The record is qualitative except for time, which can be read to approximately 50 milliseconds.

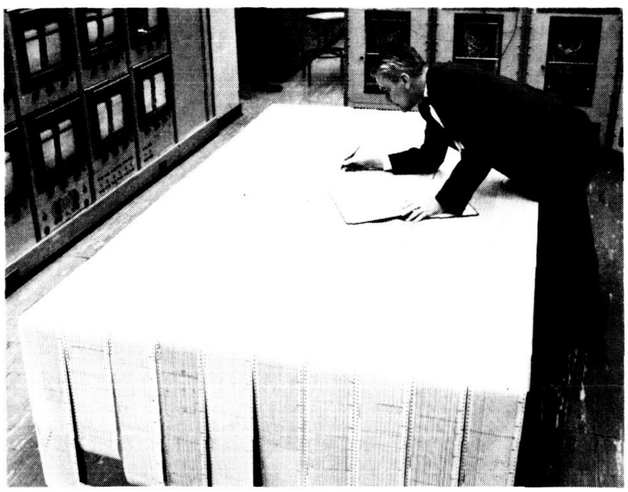

FIGURE 2. PRINTOUT OF TEST RESULTS, ESTERLINE-ANGUS RECORDER

The EA recorders were used because of the ease with which the number of information channels could be increased (i.e., by adding recorders) and because of their capability of recording simultaneous occurrences. Evaluation of test results of major systems (e.g., overall tests) is based to a considerable extent on evaluation of discrete event records. During Jupiter work, use of 200 channels was fairly common; this meant that 10 to 12 recorder charts had to be aligned carefully and evaluated simultaneously. Such evaluation is tedious, time-consuming, and susceptible to human error. It was recognized even then that there was a need for an instrument to obtain these signal changes and to print out changes sequentially with information on the channel involved, the time of the change, and the direction of change. The major problem to be resolved in the development of the needed instrument was a capability for absorbing many simultaneous changes of state.

The Digital Event Evaluator (DEE) was developed to meet the need for such an instrument (Fig. 1). Its development was begun on supporting research funding, and the final development was completed on line-program funding. As shown in Figure 3, its

516	ON	23.128
516	OFF	23.148
516	ON	23.156
516	OFF	23.172
019	OFF	23.508
466	OFF	23.508
486	OFF	23.528
488	OFF	23.532
515	OFF	23.656
492	OFF	24.728
490	OFF	24.984
494	OFF	24.984
498	OFF	24.984
008	OFF	25.264
003	OFF	25.700
005	OFF	25.700
006	OFF	25.700
010	OFF	25.700
135	OFF	25.700
171	OFF	25.700
172	OFF	25.700
187	OFF	25.700
362	OFF	25.700
461	OFF	25.700
537	ON	25.700
CYCLE		25.704
012	OFF	25.708
016	OFF	25.708

FIGURE 3. PRINTOUT OF TEST RESULTS, DIGITAL EVENT EVALUATOR

output record is simplified and greatly reduced in size. As a consequence, the possibility of error in evaluation of the readout data is reduced. The time resolution of events is much more accurate, being approximately 4 milliseconds. Current test reports show an additional advantage: the DEE frequently picks up error information that could not be detected with the previous equipment. The DEE is now in use at all stage checkout areas and at the launch site (Kennedy Space Center).

B. COMPUTER METHOD FOR INSTRUMENT CALIBRATION

Inflight calibration of instruments, after the completion of manufacturing assembly, has posed several problems for a long time. In general, a given stage condition or function is measured by a transducer, the output of which is appropriately modified by a signal conditioner and passed along for telemetry transmission. A simple system for the instrument calibration of earlier space vehicles is illustrated diagrammatically in Figure 4. The

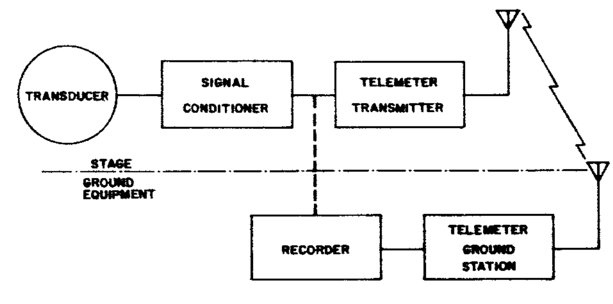

FIGURE 4. OBSOLETE METHOD FOR INSTRUMENTATION CALIBRATION

vertical dashed line represents a capability for hardwire connections to a recording facility so that one could determine whether a signal was within calibration tolerance before it reached the telemetry transmitter. The normal flow of a transducer/signal-conditioner system is from calibration to bench-level-quality verification, to installation into a stage, and to reverification and adjustment aboard the stage to ensure the maintenance of proper tolerance. This has always been a tedious and time-consuming task because of the large number of transducers involved.

With the advent of Saturn programs, basic improvements (Fig. 5) were made to ease some of the checkout problems associated with the system. A Digital Data Acquisition System (DDAS) was interposed between the signal conditioners and telemetry transmitters to provide a digital multiplexing function. A coaxial conductor link was made from the onboard DDAS to the ground checkout equipment, thereby providing greatly simplified access to instrument output signals. A Remote Automatic Calibration System (RACS) was added to facilitate setting the signal conditioners to known simulated inputs, thus providing an improved control capability. As a result of these improvements, control of the RACS, readout from the DDAS, and evaluation of results could be accomplished by computer.

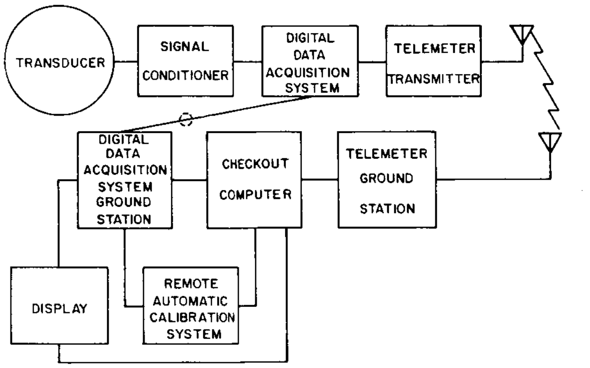

FIGURE 5. SATURN INSTRUMENTATION CALIBRATION SYSTEM

Even with these improvements, however, there remained the problem of having to adjust individually the gain settings of the signal conditioner amplifiers to correct for drift from their original settings. Consequently, an investigation of the entire complex system was initiated by MSFC in an attempt to better integrate the automatic stage checkout systems. The study was conducted by Nortronics Division of Northrop Corporation. Three possibilities for relief appeared worth investigating: modification of existing procedures by relaxing tolerances; an electromechanical servoloop; and completely automated, computer calculated and controlled calibration.

For reasons of feasibility and practicality, the completely automated, computer calculated and controlled calibration method was chosen for use. The method is illustrated in Figure 6, which is a representation of a calibration curve for a transducer and signal conditioner. The vertical axis is the value to be measured, and the horizontal axis is the telemeter output. The solid sloping line is the original calibration curve. A shift in the amplifier is represented by a dashed curve rotated about the origin. There are two calibration points built into the signal conditioner, one at a high point on the curve and one at a low point. Access to both points is controlled through the RACS, either manually or by computer. A given value of the sensed measurement on the shifted curve shows a different output from that of the original curve. Thus, the value read from telemetry would be incorrect if the curve shifted.

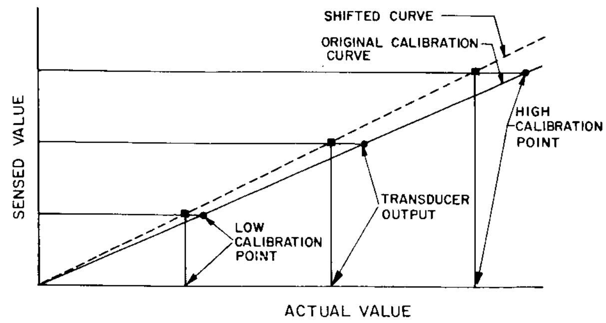

FIGURE 6. CALIBRATION CURVE FOR A TRANSDUCER AND SIGNAL CONDITIONER

Two facts were established to support further progress: transducers never drift or shift, and the amplifier's drift or shift is such that the output curve retains its original shape. Therefore, if the original bench calibration is established and the information fed to the computer, a program may be used to read out the existing calibration points, and the computer can calculate the amount of change for any given point on the curve. For simplification, the curve shown in Figure 6 is a straight line, although this is not essential to the process. This method offers the capability for using computer programing for calibration of flight instrumentation right from the beginning, once bench test data have been established. An upper limit for allowable drift can be established beyond which amplifiers are replaced. Other than this, no further need exists for the laborious manual methods previously used. Even further, it is entirely applicable to a situation in flight, orbit, or deep space in which knowledge by the astronaut of transducer calibration can be vital, and external adjustment difficult or impossible.

C. CONTROL METHODS FOR CHECKOUT

One of the more pressing needs for improvement in automated checkout is a means of allowing the test personnel adequate control of the process. This requirement is generally satisfied in a manual system through the use of manual switches and a predetermined test procedure.

Figure 7 shows the types of control which have been common in the past, in which each function is accomplished by a manual operation, the timing and necessity having been established by the procedure and the operator's assessment of information shown by the indicators.

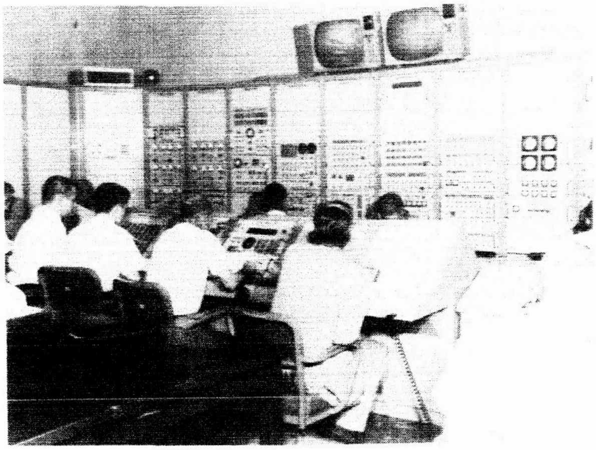

FIGURE 7. USE OF MANUAL CONTROL FOR CHECKOUT

Computer-controlled tests generally proceed at a rate which makes it difficult for a person to keep up with the current step of the procedure. Nevertheless, manual intervention in the computer operation will be required at times, regardless of hard-wired safety controls and programed alternatives. Manual intervention is required when the computer has no alternative routines upon which to fall back, or when it has exhausted the routines which exist and then reports out the exception. (Figure 8 is an example of such a printout.) The person conducting the test assesses the symptom indications which are available, the location of the problem within the test procedure, and the major system which is in trouble. He then corrects or circumvents the difficulty and continues the test, or in some cases terminates the test in order to make necessary repairs.

```
READY
TEST
PROG?
77

START  77  0751  08-15-64

SEGMENT 000
SEGMENT 001
SEGMENT 203
SEGMENT 300
STEP     1
NO GO'S
D    25
STEP     3
NO GO'S
D   431
STEP     6
NO GO'S
D    90
D   144
STEP     8
NO GO'S
D   171
D   173 00102.
SEGMENT 000
```

FIGURE 8. COMPUTER PRINTOUT AFTER ENCOUNTERING TROUBLE

FIGURE 9. SWITCHING CONTROLS FOR MANUAL OPERATION, COMPUTER TROUBLESHOOTING

Figure 9 shows one arrangement of switching controls to allow selective manual operation for troubleshooting independent of the computer. At best, this provides a cumbersome approach to the problem. Manual capability to make some changes in computer memory to circumvent difficulty, change values, and so on, also exists. However, this procedure depends upon an intimate knowledge of the computer and its programing, and can be dangerous because of the possibility of operator error or because of unforeseen effects on later portions of the program which are iteratively dependent on the modified section.

Solutions to problems of this type have been of a gross nature. For example, the well-known "panic button" can initiate a programed shutdown. Another possibility is illustrated in Figure 10, which shows a sight-operated switch whose function is based on light refraction from the operator's eye. The switch-

FIGURE 10. SIGHT SWITCH

ing operation is initiated when the operator turns his eyes to look at the switch. Sensitivity can be varied so that an involuntary glance will not operate the switch. The sight switch would be useful for setting a safe-condition system into operation (e.g., venting a tank to relieve excess pressure buildup), for bringing specific items up for display, etc. The sight switch is a single-switching operation and therefore is also a gross control. The switch was developed under contract by Spaco as part of the investigation by MSFC into the general problems of stage checkout control.

Refinements of the control problem will not come easily. They are dependent upon intimate knowledge of all systems involved in a given operation, and will vary from one system to another, so that general solutions will be infrequent. MSFC is continuing its investigation into specific areas of the Saturn V checkout systems to determine how refinements can be made in existing systems. As time and funds become available, it can be expected that more detailed solutions will be obtained.

IV. CHECKOUT DISPLAY REQUIREMENTS

A knowledge of existing conditions and symptoms is required for adequate checkout control. Three situations in automated checkout requiring information presentation are: real-time running status, symptom and system information for troubleshooting, and assistance in test procedure generation.

Figure 11 illustrates one means of providing information on real-time status. This photograph shows a bank of lights arranged to indicate existing status, as well as the progression of a sequence of events. This is useful during a rapidly sequenced operation such as engine ignition, but is generally not sufficient in itself.

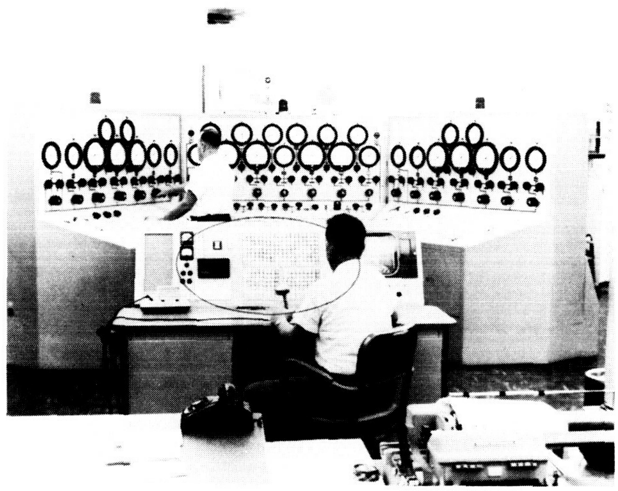

FIGURE 11. LIGHT INDICATORS FOR RAPID SEQUENCE TESTING

Figure 12 shows a panel with meters for information indication. These are useful in static condition, but generally are not useful during a computer-controlled test unless an observer for each meter or small group of meters is present to monitor the overall test status. The rapid progression of the test sequencing makes such use almost of no benefit to a test conductor.

The person conducting the test requires an overall awareness of test status and progress and a capability which will enable him to anticipate an action

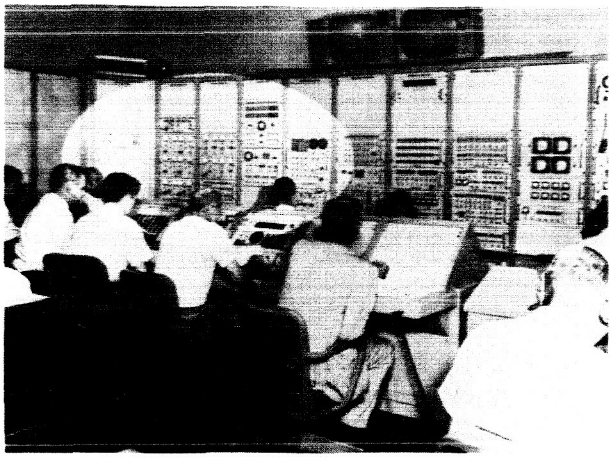

FIGURE 12. USE OF METERS FOR INFORMATION INDICATION

he must take. The combination of a computer and a cathode-ray-tube (CRT) display offers a good partial solution to the test conductor's problem. Many types of CRT displays are available. The problem of use in stage checkout is what to show on the display, and to what quantitative depth.

A simple analogy would be a situation in which one must know, from a remote location, the position at every instant of time of an individual walking from one corner of a room diagonally to the opposite corner. By placing sensors in a grid pattern one could place x and y digital indicators in the remote location and with a certain amount of estimating and a grid map, ascertain the position. A simpler solution would be to use a closed circuit television system with a screen in the remote location. The viewer could then have the necessary information instantly.

A matrix of variables with current quantitative status can be shown on a CRT screen. Table I shows a sample of what such a matrix could include. It is not intended to be typical, but to show a cross section of the type of information and how it is presented.

Studies as well as experience in checkout indicate that a person conducting a test requires qualitative real-time information analogous to the closed circuit television example while the computer is proceeding with a test. Therefore, a flow diagram, as indicated in Figure 13, would be very useful. In this case, the "flow" in the test can be indicated by a cursor, shading, or other means. Manual estimation is not required, and events requiring anticipatory action can be clearly indicated. When an involuntary computer "stop" occurs, the position of the stop is clearly shown, and it indicates a beginning point for remedial action.

TABLE I. SAMPLE MATRIX OF VARIABLES FOR CRT DISPLAY

	VOLTS	AMP.	N/m^2 (psig)	N/m^2 (psia)	ON/ OFF
BUS # 1	28.5	14			On
BUS # 2	29.2				Off
LOX TANK PRESSURE			310 k (45)		
FUEL TANK PRESSURE			172 k (25)		
TAIL SECTION PRESSURE				41 k (6)	
WATER PRESSURE			1 M (150)		

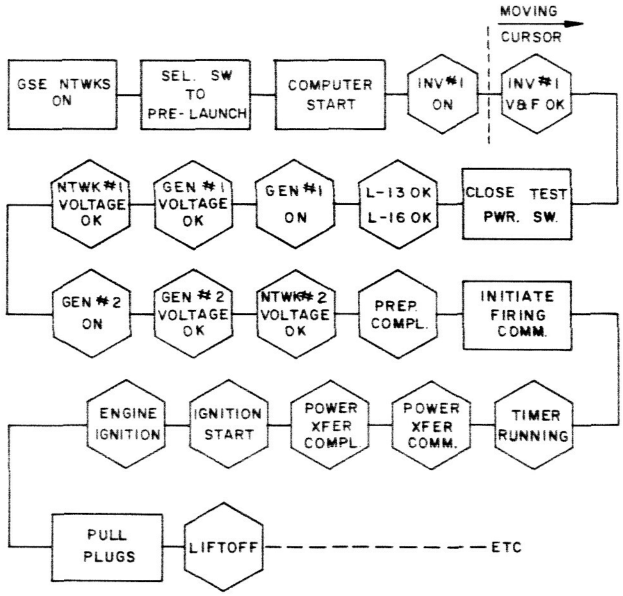

FIGURE 13. SAMPLE FLOW DIAGRAM FOR REAL-TIME PRESENTATION

When a stop has occurred, the conductor of the test must determine the nature of the problem, which frequently lies with a major subsystem of either the stage, the ground, or both. Because of the complexity of both stage and checkout equipment, the components involved may be located on several different pages of a large number of drawings. Tracing through all these to pinpoint the trouble can cause a number of problems, not the least of which is error in diagnosis. For several years, test engineers have sketched in extra information on drawings at various places to simplify this tracing operation. Figure 14 shows a composite schematic of a fairly complex system which could be depicted in its entirely on as many as ten pages of stage and checkout system drawings. A number of details have been omitted to simplify the representation and bring together the essential elements to form a complete "picture" of the system. From this point it is comparatively easy to begin to troubleshoot the system by referring to the detailed documents as necessary.

information presentation, such as projection from microfilm, could be used to overcome the digital storage problem, although information would not be easily accessible. Magnetic tape offers a solution, although accessibility is a problem here also. A disk file may turn out to be the answer to the problem, since it can provide rapid access to its stored information. Also under investigation is the compatibility of these approaches with existing checkout systems.

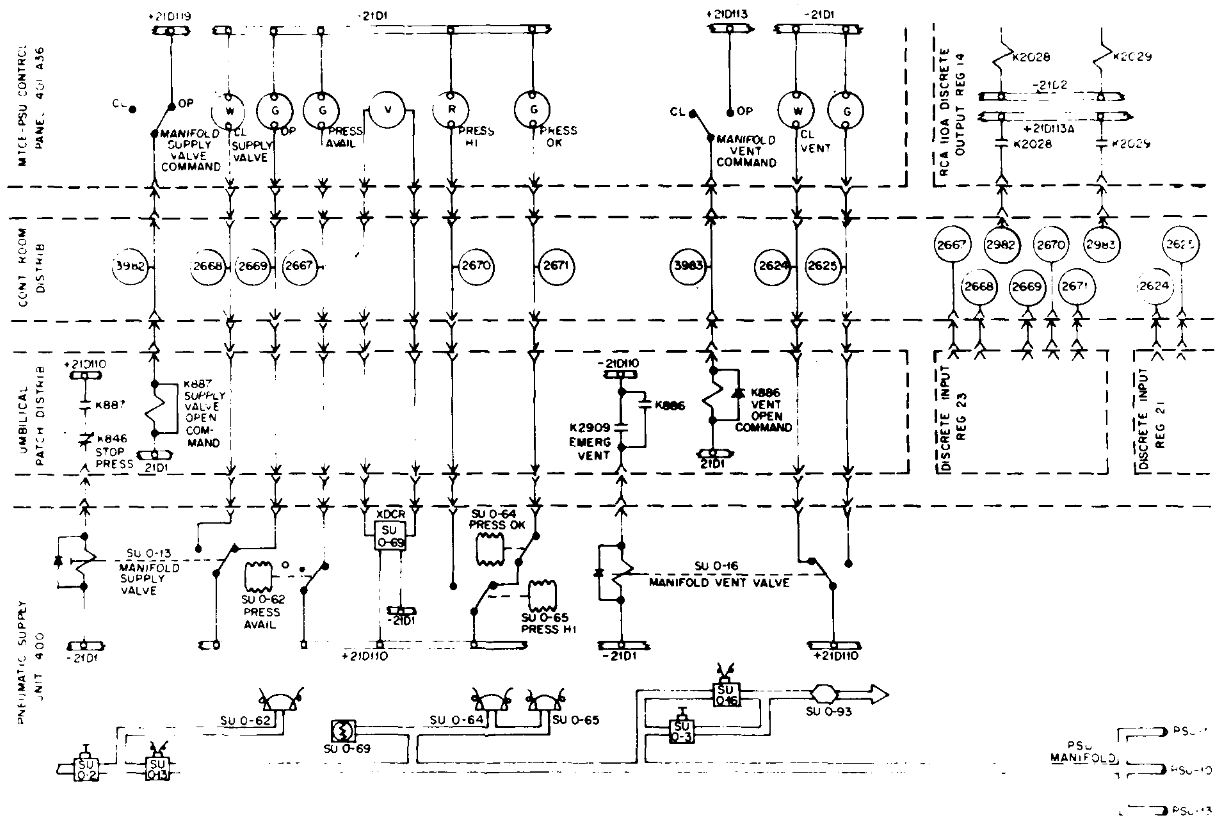

FIGURE 14. COMPOSITE SCHEMATIC OF AN INTRICATE SYSTEM

Studies have indicated that it is feasible to present this type of information on a CRT for troubleshooting. The launch site display system, for example, is capable of handling such a presentation in some respects. At present, MSFC is investigating the feasibility of digital storage in which all necessary composite schematics and a document "generation" breakdown (by divisions, subdivisions, etc.) could be displayed on a cathode-ray tube.

One disadvantage of digital storage is the large amount of memory required. Other approaches to

V. SINGLE PARAMETER TESTING

Single parameter testing deals with the introduction of a single input signal into a device, and the observation of all outputs for both normal response indications and deviations from normal. The feasibility of this technique has been established by two studies: one on the stable platform system (Emerson Electric, supervised by Astrionics Laboratory), and the other on the fundamentals of signals and network responses, (General Electric, Daytona, supervised by Quality and Reliability Assurance Laboratory).

A variety of input signals, such as a sine wave, a complex wave, a step-function input, or a growing exponential function, may be used. Considerations affecting the input signal are magnitude, time duration, necessity for repetition, and shock effect on the system under test. As a result of the input signal, various output signals from a given device are obtained. The best combination of these output signals, for a given input, must be chosen to provide a true "fingerprint" (i.e. precise identification) of the system being tested. The output signals should show a significant deviation in one or more parameters in the presence of an abnormality in order that fault indications may be observed. For maximum benefit, the output signal should be capable of computer analysis.

Achieving the proper balance for solutions of all the requirements indicated is the major problem involved. One study has indicated that a growing exponential function is the more desirable input up through third-order linear systems. A specific signal input and/or output "fingerprint" will exist for each item to be tested; like items should be capable of utilizing the same type input signal.

The advantage to single parameter testing is its simplicity in terms of testing. All that is necessary for its use is a capability to provide the input signal and to read and analyze the output. The outputs of most onboard devices are available, and computer analysis capability exists in the ground equipment. For each device to be tested in this manner, the only additions for existing onboard stage systems would be the signal source and input capability requirements. This could be approached in the same manner as the calibration provision in the signal conditioners for the instrumentation system. The approach thus becomes economical and practical, as well as technically feasible.

N66 35978

IMPROVEMENTS IN STRUCTURAL NONDESTRUCTIVE TESTING

By

R. W. Neuschaefer

SUMMARY

Advanced methods of nondestructive inspection of structural materials are described in this report.

A high-speed radiographic system has been designed for inspecting bulkhead welds of Saturn I-C propellant-fuel tanks. This system has saved half the time formerly used in radiographic inspection and has minimized work stoppage by reducing radiation hazards.

An ultrasonic inspection method, complementing the radiography method, has been developed for inspecting seam- and spot-weld joints in type 2219 aluminum. This is a quick inspection method and it provides a permanent, printed record. It also can identify spurious weld defects (enigmas) more rapidly than radiography can.

The feasibility of identifying various tempers of type 2219 aluminum has been investigated through application of a technique of eddy-current induction and measurement. The "O" condition was found to be easily identified, T62 temper the most difficult to identify, and T31, T37, T81, and T87 falling in between these extremes.

Formerly, hydrostatic testing of tapered-wall tanks was feasible because flight conditions could not be simulated with conventional test methods. To solve this difficulty, a zone-gradient pressurization system was conceived, and pressure seals and test fixtures designed, for testing a model-sized straight-wall tank under accurately simulated flight loading. The successful full-scale application of this system should significantly affect the future development of lightweight tapered-wall propellant tanks.

I. INTRODUCTION

In recent years the complexity of manufactured items has increased, while design margins have been reduced. As a consequence of these changing conditions, advancements in inspection techniques have been especially necessary.

The Analytical Operations Division of Quality and Reliability Assurance Laboratory has been specifically concerned with improving nondestructive techniques for inspecting structural materials. Some of its achievements in improved test or inspection methods are described in this report under investigations in a semiautomatic radiographic inspection system, ultrasonic techniques for inspecting spot and seam welds, eddy-current techniques for sorting tempers of type 2219 aluminum, and zone-gradient hydrostatic testing.

II. SEMIAUTOMATIC RADIOGRAPHIC INSPECTION SYSTEM

Industrial radiography has been in use since the start of the twentieth century for examining weldments, castings, and composite structures. The Saturn program, with welded tanks and very narrow design margins, has required a reevaluation of the radiographic methods previously employed. The first radiographic techniques used at MSFC possessed a radiation hazard and were slow; therefore, the primary consideration was given to the design and manufacture of a safe, high-speed radiographic system to assure the quality of S-IC bulkhead welds.

The system that was developed as a joint MSFC/ Boeing Company effort (Fig. 1) uses two 31-meter

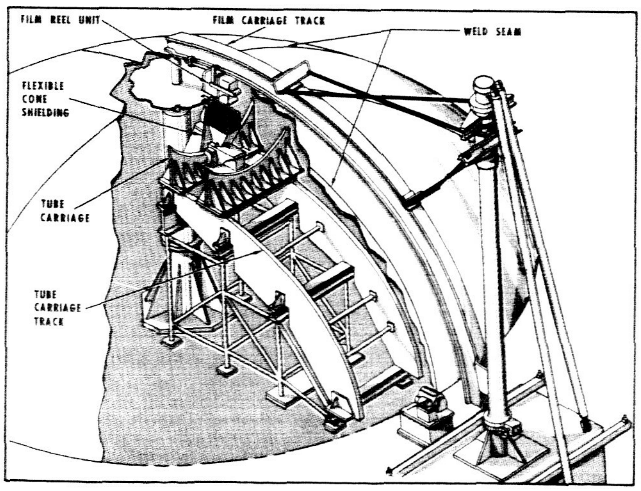

FIGURE 1. SEMIAUTOMATIC X-RAY SYSTEM

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(100-ft) reels of film and a semiautomatic electrically controlled advancement of film, a film positioning unit, and an x-ray tube. The operation of this system is controlled from a single console.

There are five major groups of equipment in the new system:

1. The film-transfer unit, with reels driven by electric motor for rapid loading of x-ray film (Fig. 2)

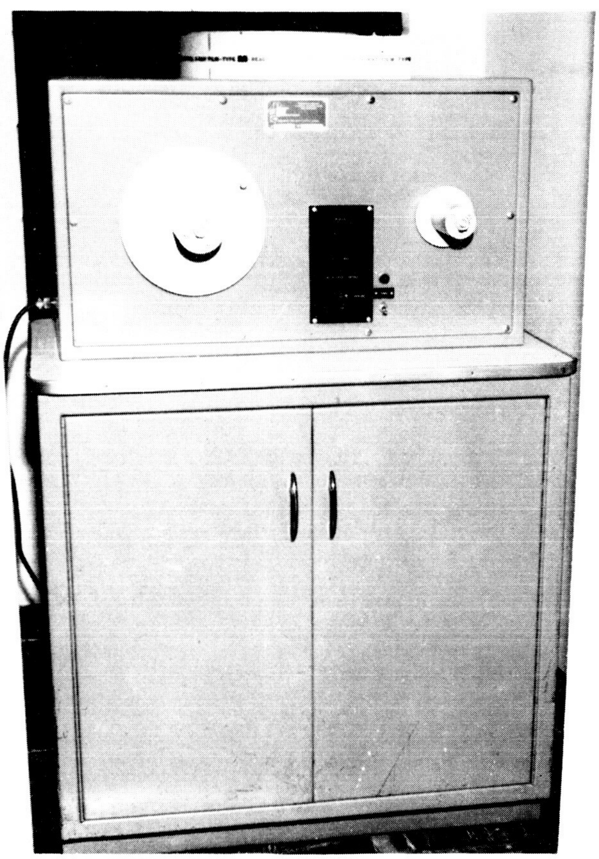


FIGURE 2. FILM-TRANSFER UNIT

2. Semiautomatic x-ray equipment consisting of several units which position the film and welds in correct alignment (Fig. 3)

3. The semiautomatic film-wrapper stripper which strips the lightproof paper wrapping from the films so that it may be automatically processed (Fig. 4)

4. The Pako semiautomatic processing equipment which develops, fixes, washes, and dries the film (Fig. 5)

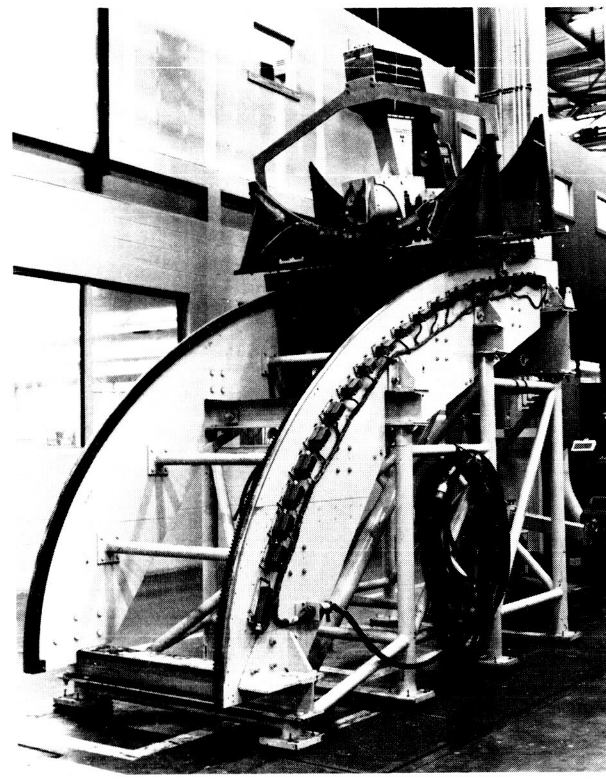


FIGURE 3. SEMIAUTOMATIC X-RAY EQUIPMENT

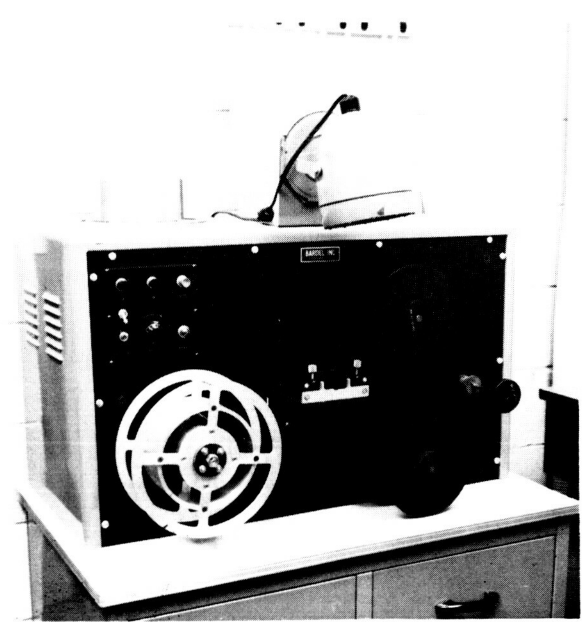


FIGURE 4. SEMIAUTOMATIC FILM-WRAPPER STRIPPER

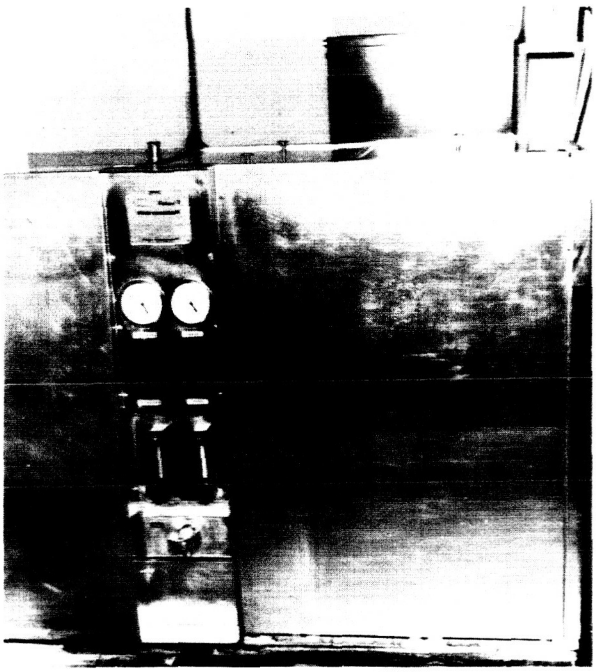


FIGURE 5. PAKO SEMIAUTOMATIC FILM PROCESSOR

5. A semiautomatic film-viewing console, which provides optimum film-viewing conditions and facilitates the handling of film on motor-driven reels (Fig. 6)

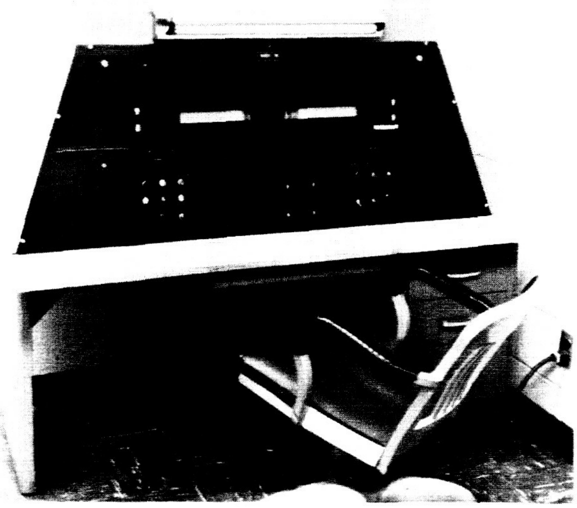


FIGURE 6. SEMIAUTOMATIC FILM-VIEWING CONSOLE

The new radiographic inspection methods have several advantages over the previously used ones. The total manhours required for exposing, processing, and reviewing film is approximately 50 percent less. The savings are not only in inspection time, but in the total time that the work area must be cleared. Because the radiation hazard has been reduced, personnel may work within 3 meters (10 ft) of the unit instead of the previous 15 meters (50 ft). Therefore, work stoppage has been reduced to a minimum. The transport fixture, moreover, is adaptable for ultrasonic testing.

III. ULTRASONIC INSPECTION OF SPOT AND SEAM WELDS

Although ultrasonic inspection equipment has been available since the 1940's, the specifications of the Saturn program have required the development of improved methods and equipment. Ultrasonic and radiographic inspection methods may be used to complement each other in many instances. Defects such as cracks, porosity, and inclusions in weldments may be detected by both radiographic and ultrasonic inspection methods. Ultrasonic inspection will locate and describe the serious defects (e.g., fine cracks and crack-like defects such as certain types of incomplete penetration and lack of fusion) with the highest degree of assurance, whereas radiography will more readily detect inclusions and small porosity.

The ultrasonic inspection techniques developed and applied by Quality and Reliability Assurance Laboratory are a new and important tool for the evaluation of spot and seam welds. The two ultrasonic methods employed consist of an angle beam-through transmission technique for spot welds, and a pulse-echo technique for seam welds. The angle beam-through transmission technique uses a transmitter and a receiver.

Research has been conducted principally in the field of wave propagation utilizing collimated probes, since commercially available ultrasonic equipment does not provide high resolution. A through-transmission ultrasonic system based on this research has been developed using small collimators capable of resolution surpassing that of commerically available probes. This development (Fig. 7), which is available for production use, has been engineered for scanning spot welds and for printing out the contour of the nugget at the interface.

For an ultrasonic evaluation of seam welds in plate material such as S-IC gores and skins, initial testing to determine technique has been per-

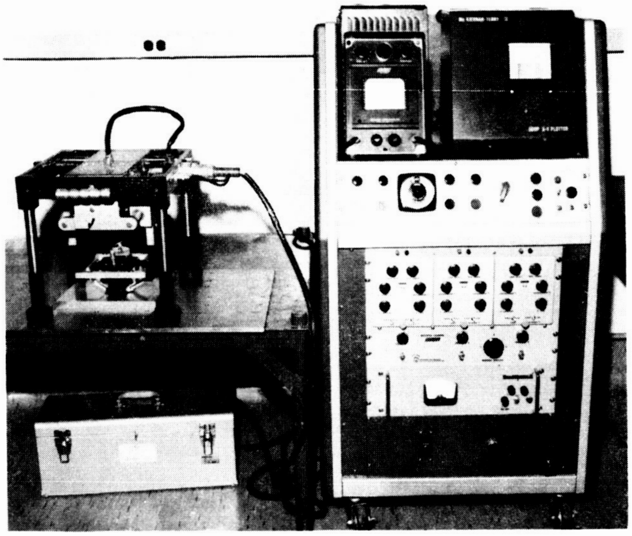


FIGURE 7. ULTRASONIC SPOT-WELD SCANNING SYSTEM

FIGURE 8. PORTABLE ULTRASONIC INSPECTION SYSTEM

formed utilizing an ultrasonic transceiver (the Krautkramer USK-4, Fig. 8). Pulse-echo techniques also have been used in this investigation. Internal porosity, cracks, incomplete penetration, and lack of fusion can be readily detected as a part of production inspection.

It was necessary to develop an automated scanning system in order to shorten the inspection time and provide a permanent inspection record. The result of this development was the simulated immersion-probe adapter for use on tooling developed for the semiautomatic radiographic system.

An ultrasonic automatic scanning and recording system (Fig. 9) was developed which produces one of the fastest "C" scans or facsimile recording of any equipment available.

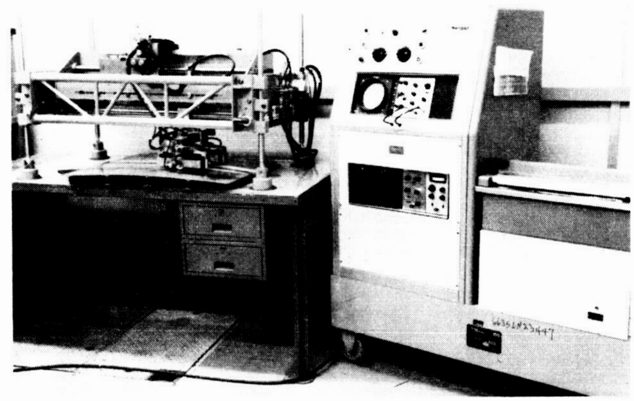


FIGURE 9. ULTRASONIC HIGH-SPEED SCANNING AND RECORDING SYSTEM

An example of the savings in money and time which can be attributed to ultrasonic testing occurred when several gore segment welds were rejected when radiography had disclosed what appeared to be a lack of sidewall fusion. A subsequent ultrasonic inspection revealed the indications to be radiograph enigmas (Fig. 10), believed to be caused by metal twinning. Although enigmas may be resolved by radiographing the material from several angles, ultrasonic inspection is more rapid; consequently, the technique currently is being employed to complement radiographic inspection.

IV. EDDY-CURRENT TECHNIQUES FOR SORTING TEMPERS OF TYPE 2219 ALUMINUM ALLOY

The temper of fabricated material for incorporation into space vehicles may not be known precisely because incomplete or erroneous documentation accompanies the material received. The true condition of the material in the past could be ascertained only by destructive testing methods such as tensile-strength and hardness testing. These tests were time-consuming and difficult to perform because of the large size of some of the material. In addition, the destructive techniques are inherently undesirable.

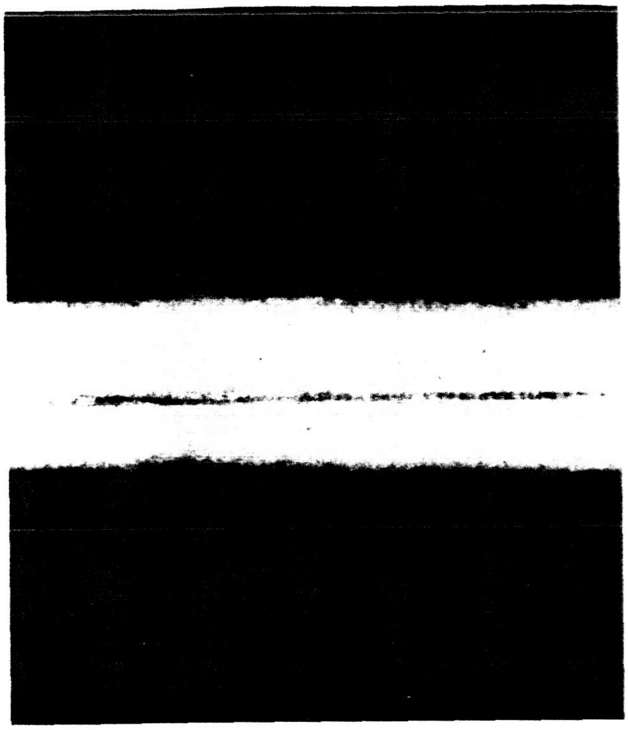


FIGURE 10. ENIGMA IN THE RADIOGRAPH OF A WELD

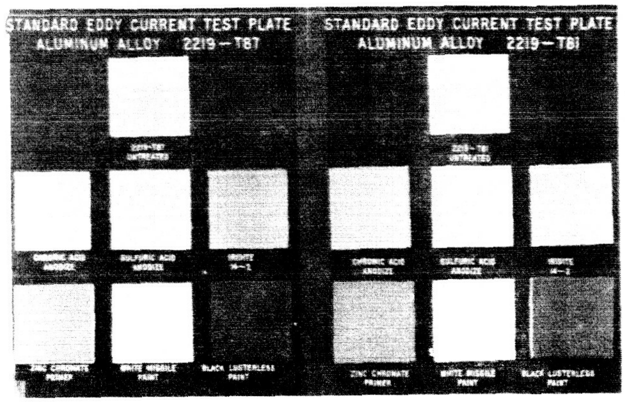


FIGURE 11. EDDY-CURRENT TEST PLATES

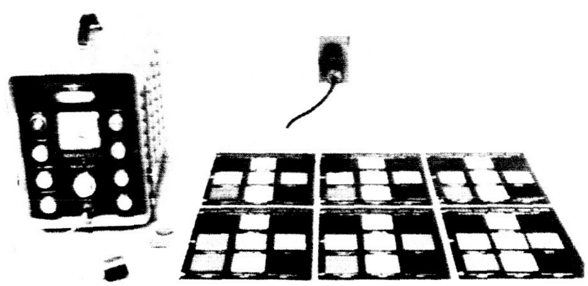


FIGURE 12. EDDY-CURRENT TEST SETUP

Because of the disadvantages stated, a research project was initiated to determine the feasibility of using commercially available eddy-current testing instruments to differentiate the various tempers of type 2219 aluminum alloy.

Eddy currents are induced into a metal specimen when it is placed in the field of a coil carrying alternating current. The impedance or opposition to the flow of induced eddy current is a function of the metal's electrical conductivity, which is influenced by the temper of the metal.

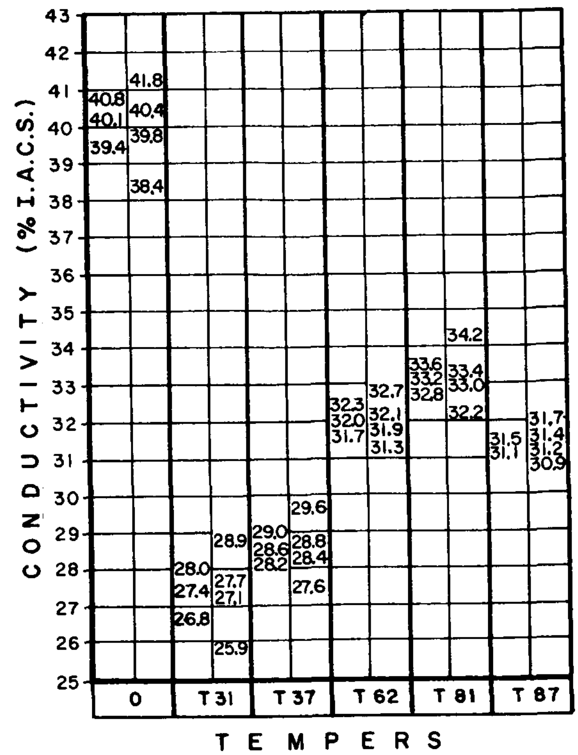
Test specimens were surface treated with coatings representative of those employed on space vehicle flight hardware for an evaluation of the influence of coatings on the instruments' temper-sorting capability. Figure 11 shows some representative surface specimens of two tempers which were subjected to eddy-current tests. Figure 12 shows the test setup using Magnaflux Corporation's eddy-current tester (FM-100), which is the most sensitive instrument evaluated to date.

Because there were a limited number of samples available, it was decided to conduct this initial statistical analysis to 95-percent confidence limits. A further study to refine the data will be conducted when more measurements are obtained.

The raw data of this study were analyzed statistically for a determination of the following: (1) the significance of coating variations as compared to random variation together with operator effect and instrument error or drift (or both) and (2) the 95-percent confidence limits for the samples, and the number of samples for each temper.

An analysis of variance test was used to determine the significance of temper as compared to coating and residual. The F-ratio tests indicated that the effect of temper was of extremely high significance as compared to residual variation and coating. The temper data were analyzed to obtain values to be expected from all samples of each temper.

The feasibility of sorting tempers of 2219 aluminum alloy is summarized in Figure 13. Conductivity of the "O" condition or annealed material can be readily identified. The conductivity of tempers T31 and T37 overlap strongly. Temper T62 is partially overlapped by tempers T81 and T87 and is the most difficult to identify.



- VALUES IN LEFT SIDE OF EACH COLUMN ARE MEAN ($\bar{X}$) AND 95% LIMITS ($\bar{X} \pm 1.96s$) FOR TESTED SAMPLES.
- VALUES IN RIGHT SIDE OF EACH COLUMN ARE ESTIMATED RANGES OF MEANS (μ) AND 95% LIMITS FOR ALL TEMPER SAMPLES OF SIMILAR COATING.

FIGURE 13. CONDUCTIVITY CHART FOR TYPE 2219 ALUMINUM ALLOY

V. ZONE-GRADIENT HYDROSTATIC TESTING

Hydrostatic testing is an important nondestructive testing method which is employed to verify structural integrity of S-IC tanks. At times this method may be destructive, but even in these cases worthwhile data are usually obtained from the test.

Hydrostatically proof testing propellant tanks to full operating pressure is customary in the space industry. The proof test is necessary because of the narrow margins imposed on vehicle design by weight considerations. As a result of these narrow margins, tanks have been designed with yield-to-design load ratios of 1.1 to 1.0, which means that any defect in raw or fabricated material can result in a catastrophe. Most defects will be revealed by in-process inspection; but only a full-load proof test can give the assurance required for a major vehicle, especially a manned vehicle.

Tapered-wall-thickness designs now used for large tanks cannot be tested by conventional means because conventional hydrostatic test conditions differ from those of flight. For example, water used in the test tank differs in density from flight propellant, and the test tank is not under the force of flight acceleration. (This is not a problem related to designs for constant wall thickness.)

The magnitude of the problem encountered in the hydrostatic test of large vehicle tanks can be readily seen by the analysis of the hypothetical tank shown in Figure 14. This tank is 19.5 meters (64 ft) long,

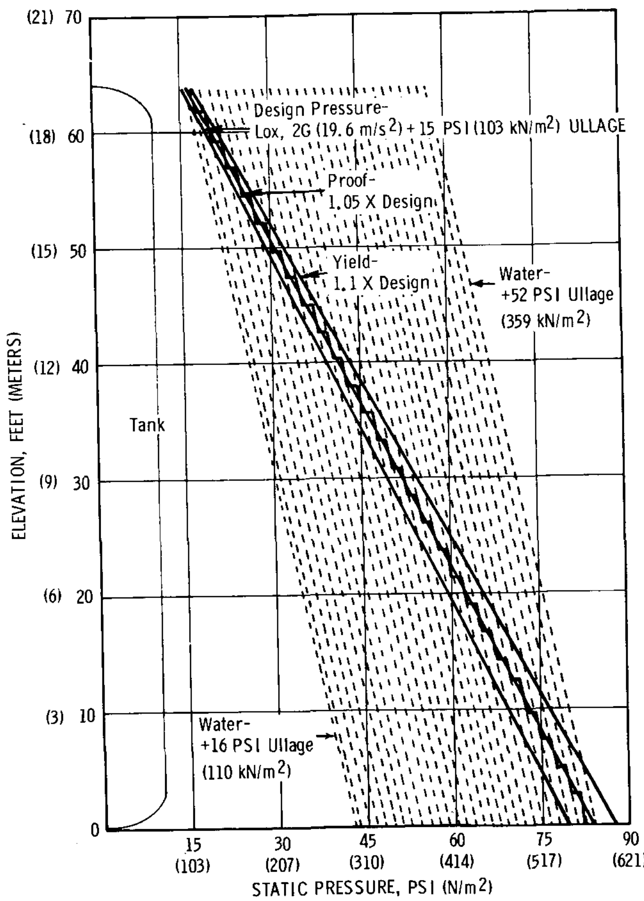


FIGURE 14. HYPOTHETICAL HYDROSTATIC TEST TANK

10 meters (33 ft) in diameter, and is subjected to an ullage pressure of 103 kN/m^2 (15 psig) and an acceleration force of 19.6 m/s^2 (2 g). The tank configuration and condition are similar to those of a Saturn

S-IC liquid-oxygen tank, under severe forces, except that the values have been rounded and all structural loads other than pressure have been ignored.

The maximum differential pressure of 441 kN/m^2 (64 psi) at the aft bulkhead is a function of liquid-oxygen density, head, acceleration, and ullage pressure. In comparison, the same tank filled with water for hydrostatic testing exhibits a maximum differential pressure of 191 kN/m^2 (27.7 psi), which is a function of water density, acceleration, and head. Under this condition, the aft bulkhead is pressurized only to 294 kN/m^2 (42.7 psig), which is 250 kN/m^2 (36.3 psig) under test pressure when the forward bulkhead is at full load. Conversely, the forward bulkhead is overloaded 250 kN/m^2 when the pressure at the aft bulkhead is at flight pressure.

The first condition is unacceptable because it does not provide the required assurance. The last condition, although a usable solution, is also undesirable because it imposes a design requirement for test that is heavier than needed for flight. In the example given, the test load would be 340 percent of the flight load, with a significant increase in tank weight.

The above conditions are delineated as height versus pressure plots in Figure 14. The dashed lines represent a family of pressure gradients obtained with water in a 9.8 m/s^2 (1 g) acceleration environment by varying ullage pressure in increments from 110 kN/m^2 to 393 kN/m^2 (16 psi to 57 psi). The three solid lines represent the design conditions, the required test condition, and the yield pressure. The extreme left and right gradients illustrate the conditions obtained by conventional methods when the test requirements of the upper and lower bulkheads are met.

Figure 15 illustrates a conception of the zone-gradient pressurization. This pressurization method consists of applying pneumatic pressure to the exterior of the tank to develop an acceptable approximation of the required gradient. This is accomplished with a dome-head section and a number of skirt sections enveloping the tank. The tank is segmented into a series of pressure zones isolated from each other through the use of inflatable seals.

Air pressure is applied directly to the external surface of the tank to provide infinite conformability, thus eliminating the local load discontinuities that would result from bladders. The inflatable seals (Fig. 16) are suited for zone isolation, they provide adequate clearance for fixture placement, and, when inflated, have sufficient conformability to adequately seal around welds and other minor irregularities.

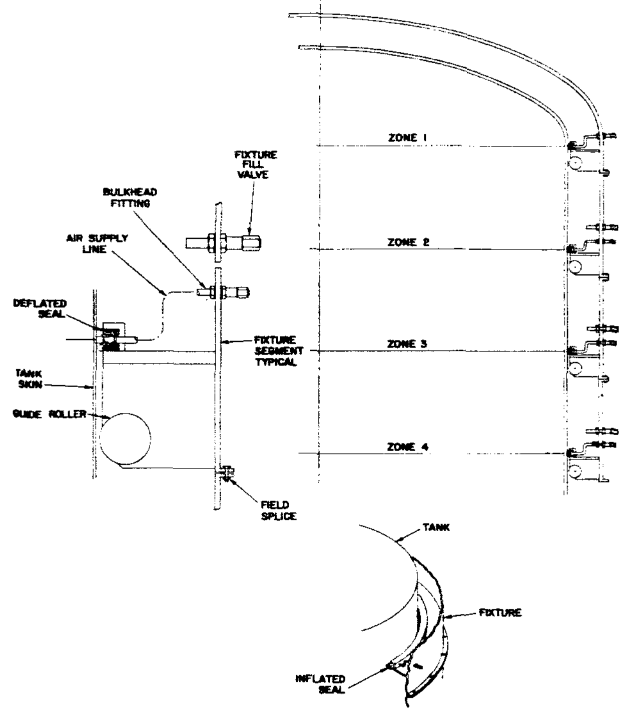


FIGURE 15. ZONE-GRADIENT PRESSURIZATION CONCEPT

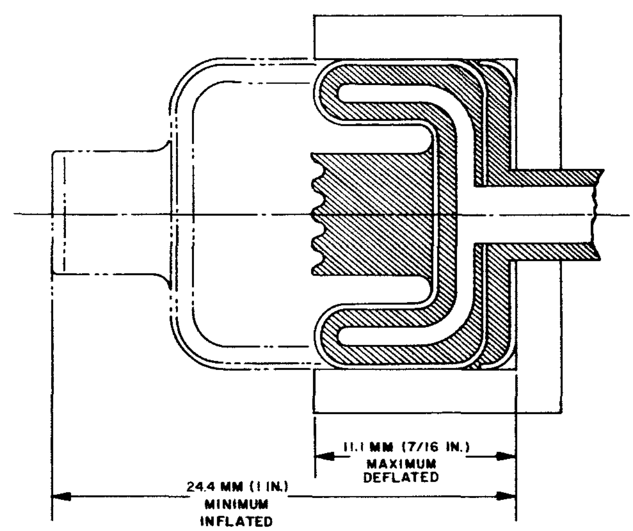


FIGURE 16. INFLATABLE SEAL

The pressure on the tank skin is the difference between internal and external pressure. Any desired gradient can be approximated by establishing the appropriate pressure in each external zone. The desired pressure gradient for testing the hypothetical tank in Figure 14 and a close approximation of this gradient, which can be realized using the zone-gradient method, are shown as the proof pressure and the stepped pressure gradients in the figure. The pressure, although a function of height, never exceeds the yield strength nor goes below the design strength.

Problems were anticipated in the critical mechanical handling of the test fixture and in designing suitable seals. A model zone-gradient fixture was designed and built to prove the feasibility of the conception. The model fixture was assembled around a 1.8 m (70 in.) tank (Fig. 17), the inflatable seals were pressurized, and the zone pressure increased in accordance with the sequential pressurization schedule given in Table I. The pressure increments in all zones were typical of the stepped line shown in Figure 14. All pressures were maintained without difficulty and all seals were satisfactory.

The technical feasibility of the pressurization concept has been demonstrated; its economic feasibility now must be determined. This effort will require cost and design studies for a full-size zone-gradient system of a specific stage, cost- and weight-saving studies for the optimum tapered tanks on that stage, and a comparison of the two studies to determine gain in payload.

VI. CONCLUSIONS

No single nondestructive testing method will detect all defects in all materials. Radiography had been considered by some as a panacea for all inspection ills when it was first discovered, and ultrasonic techniques offered similar promise. However, each of these methods has been shown to have limitations.

Promising new technologies under development are infrared and microwave inspection methods, each system having certain inherent advantages and disadvantages.

The principal difficulty with inspecting today's advanced structures is that testing methods required to adequately assure quality require much time for their development. Consequently, quality assurance engineers are finding it necessary to improve and intensify quality-assurance support during advanced structures development.

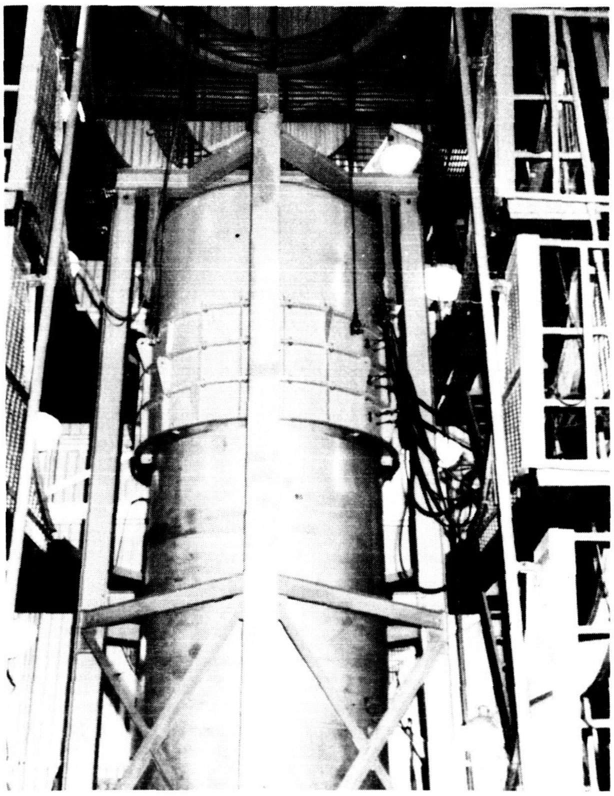


FIGURE 17. ZONE-GRADIENT FIXTURE ASSEMBLY

TABLE I. SEQUENTIAL PRESSURIZATION SCHEDULE

Event	Seal 1	Zone 1	Seal 2	Zone 2	Seal 3	Zone 3	Seal 4	Zone 4	Tank
Fill and pressurize tank									15
Install zone 1 fixture				no change					
Inflate seal 1	25								"
Pressurize zone 1	"	5							"
Raise tank pressure	"	"							20
Install zone 2 fixture				no change					
Inflate seal 2 increase seal 1	30	"	25						"
Pressurize zone 2	"	"	"	5					"
Increase zone 1	"	10	"	"					"
Increase tank pressure	"	"	"	"					25
Install zone 3 fixture				no change					
Inflate seal 3, increase seals 1 and 2	35	"	30	"	25				"
Pressurize zone 3	"	"	"	"	"	5			"
Increase zone 2	"	"	"	10	"	"			"
Increase zone 1	"	15	"	"	"	"			"
Increase tank pressure	"	"	"	"	"	"			30
Install zone 4 fixture				no change					
Inflate seal 4, increase seals 1, 2, and 3	40	"	35	"	30	"	25		"
Pressurize zone 4	"	"	"	"	"	"	"	5	"
Increase zone 3	"	"	"	"	"	10	"	"	"
Increase zone 2	"	"	"	15	"	"	"	"	"
Increase zone 1	"	20	"	"	"	"	"	"	"
Increase tank pressure	"	"	"	"	"	"	"	"	35

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IMPROVEMENTS IN ELECTRONIC COMPONENT TESTING

By

M. J. Berkebile

SUMMARY

Improved and new methods of inspection screening of basic electronic parts and subassemblies are discussed in this report.

Investigations on monolithic integrated circuits have revealed major causes of failures. Quality and Reliability Assurance Laboratory has used this information in writing a procurement specification for an instrument to test AC and DC parameters of integrated circuits. When the equipment is in operation it will provide much needed standardization for reliable acceptance inspection of integrated circuits.

In the past, hermetically sealed relays which passed electrical inspection would fail later because of corrosion of relay contacts (atmospheric moisture had entered through undetected leaks in the seal). The difficulty of finding seal defects in acceptance testing has been simplified through the use of a nondestructive radioisotope tracer detection method. Current work is attempting to determine whether present leakage limits are adequate for extended space missions.

The reliability of soldered and welded electrical connections is not easily determined by visual inspection and often is judged by subjective criteria. Investigations were made, through contract support, to establish objective and reliable standards for verifying the reliability of such electrical connections. The solderability of component lead-connection material was determined as a basis for establishing solderability ratings. Analogous work was done for welded connections, and the results, combined with pull-test data, provided the basis for a weldability rating chart.

Electrical functional tests presently cannot indicate certain faults which will affect the operating life of a component. An infrared radiation test method of incipient failure detection is being investigated. With this method, infrared radiation patterns of normal and faulty components will be compared and, through projection, the operating life of the tested component will be calculated.

I. INTRODUCTION

The evaluation of new technology and its integration into NASA vehicle and space booster designs requires the simultaneous development of quality assurance requirements. In keeping pace with these new and amplified needs, Quality and Reliability Assurance Laboratory of MSFC has been undertaking projects that should most effectively provide a firm theoretical base for quality assurance requirements, produce new nondestructive test methods, and establish quality assurance requirements for advanced equipment, materials, methods, and processes.

A firm theoretical base for quality assurance requirements is more important in today's aerospace age than it ever was. This aspect of quality assurance was neglected in past years, with the result that the quality assurance function became very subjective. To remedy this deficiency, there has been an especially important need for research to determine correlations between primary functions and secondary phenomena. An example of such research under way at MSFC is the investigation on utilization of infrared emission to evaluate electronic equipment.

The cost, complexity, and frequent unavailability of space booster equipment generally precludes the use of destructive test methods. Consequently, the value of nondestructive test methods and equipment used to determine defective materials and components is incalculable. Work at MSFC on new nondestructive testing methods includes the use of radioactive tracers and infrared for testing the reliability of electronic components.

Integrating the requirements mentioned and then translating them to actual manufacturing conditions requires further research and development. This is known as manufacturing research. From this phase the quality assurance requirements are derived for implementation by production organizations. Examples of MSFC work leading to such requirements are the programs for defining weldability and solderability of materials and for determining critical parameters of process equipment such as welding machines.

II. QUALITY ASSURANCE REQUIREMENTS FOR INTEGRATED CIRCUITS

Since MSFC does not have specific quality assurance requirements for integrated circuits, requirements are being established by basing them upon manufacturing processes and the electrical parameters. This is being done by procuring integrated circuit devices from various manufacturers and subjecting these devices to extensive electrical tests in order to determine failure mechanisms and the most critical electrical parameters.

An idea as to the complexity of the integrated circuit is given by Table I, which lists the evolution of electronic packaging techniques beginning in the 1950's. The vacuum tube was followed by the module technique employing semiconductors with either a welded or a soldered module. To further increase component density, the thick-film and thin-film techniques coupled with multilayer interconnection boards are being utilized, and the integrated circuit packaging concept provides an even greater component density.

TABLE I. EVOLUTION OF ELECTRONIC CIRCUIT PACKAGING

Circuit; Year	Component Density, parts per cubic meter (parts per cubic foot)
Vacuum tube; 1950	35×10^3 (1×10^3)
Printed, transistor; 1955	35×10^4 (1×10^4)
Welded, transistor; 1957	35×10^5 (1×10^5)
Thin Film; 1959	35×10^7 (1×10^7)
Integrated; 1960	35×10^8 (1×10^8)

The thick-film technique (dating to World War II) allows for a high degree of miniaturization at relatively low cost. In this technique, commonly known as screened circuitry, the electrical elements and conductors are formed by depositing electrically conductive pastes or inks onto a suitable substrate, producing a functional or partially functional circuit. The conductive pastes or ink are forced onto the substrate through a fine mesh screen which is imprinted with the desired circuit pattern. Only conductors and passive electrical elements can be produced by this process (capacitors and inductors to a very limited extent). Active elements are added to the circuit by soldering. The production and tooling costs for screened circuitry are much lower, and the process parameters less critical than they are for the thin-film and silicon monolithic techniques to be discussed. A comparison of these three techniques is given in Table II.

TABLE II. COMPARISON OF THREE MICROMINIATURIZED ELECTRONIC CIRCUITS

		Screen Printed	Thin Film	Silicon Monolithic
Cost	Facility	medium	low	high
	Large Lot	medium	high	low
	Small Lot (Custom)	low	medium	high
Reliability		unknown	unknown	unknown
Isolation		good	good	poor to fair
Design Flexibility		good	good	poor

A second major method of circuit microminiaturization is the thin-film technique. Thin films (up to 10,000 Å thick) are deposited onto a substrate by any one of several methods, such as vapor deposition or sputtering. Although a great deal of research is being pursued for a method of depositing active components, at present the deposition of components, as with the thick-film technique, still is restricted to passive types. Thin films normally are deposited in a high vacuum (0.13 mN/m^2 or 10^{-6} torr), which is a disadvantageous feature of the process. Thin-film and thick-film techniques are applicable to both digital and analog circuitry. They are used primarily for linear circuits and high-speed digital applications.

Monolithic integrated circuits are more commonly used in digital applications than the deposited-film circuits mainly because of their lower cost in large quantities. The monolithic technique utilizes a silicon substrate as the basic material, and develops a complete circuit within this substrate through successive masking, etching, and diffusion processes. Resistance, capacitance, isolation regions, and active devices, thus, are encompassed in the basic material. Thin films of aluminum are used to interconnect the element areas of the substrates and to form the bonding pads to which external leads are connected.

Semiconductor integrated circuitry is susceptible to several types of failures. These can be classified within two groups, quality and time dependent. The quality failures are due to faulty workmanship. One of the most common faults, cracks and scratches in the circuitry, is caused by the improper use of the die-handling tools.

One of the time-dependent failures results from inadequate removal of etchant. When the etchant used to etch the aluminum interconnecting paths is not removed completely, it continues to erode the aluminum, eventually opening the conducting path.

Another time-dependent failure results from the interaction of circuit metals. A vacuum-deposited thin film of aluminum forms the interconnections for the circuit components (semiconductors, resistors, etc.). Gold leads, attached to the aluminum surface, connect the integrated-circuit chip to other circuitry. Interaction between the aluminum and gold may result in corrosion, called Purple Plague, which alters or opens the circuit. A similar corrosion failure, called Black Plague, results from the interaction of aluminum, gold, and silicon at their interfaces.

A procurement specification has been written for an instrument that will test the various static or DC parameters and the dynamic or AC parameters of integrated circuits. This equipment is scheduled for delivery in October 1966. At present, there appears to be no other commercially available equipment that will handle the dynamic characteristics. The procurement of this equipment for use in MSFC acceptance testing will contribute greatly to the acceptance of reliable integrated circuits and assist in providing much needed standardization.

III. LEAK DETECTION TECHNIQUES FOR HERMETICALLY SEALED DEVICES

In the latter part of 1959 and the early 1960's, relays in electrical ground support equipment used at Kennedy Space Center (KSC) often failed early in operation, and supplying replacements became a major problem. The cause of failure was traced to inadequate protection of the electrical contacts. Acceptance functional testing of relays at MSFC indicated that the electrical parameters were acceptable. However, when the relays were in the humid environment at KSC, defective hermetic seals allowed moisture to enter the relay and deposit on the relay contacts. In time, the contact resistance increased, and eventually the relay ceased to function properly.

A nondestructive method for testing the hermetic seal of the relay was sought. After several methods were investigated, a radioisotope-tracer method was selected. It uses commercially supplied equipment called Radiflo (Fig. 1).

FIGURE 1. RADIFLO INSTALLATION

The Radiflo system operates in two phases. The first phase is the soak period in which the relays are pressurized in radioactive Krypton-85 within the activation chamber (Fig. 2). While in the activation tank, the parts are subjected to a pressure of approximately 300 kN/m^2 (3 atmospheres) for a designated period. At the end of the soak period, the parts are removed from the activation area and are allowed to degas for approximately one hour.

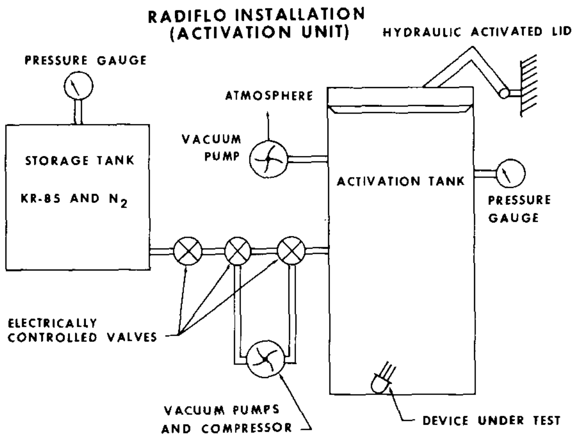


FIGURE 2. RADIFLO SYSTEM, SOAK PHASE

Counting is the second phase of the Radiflo operation. The parts are placed on a scintillation crystal electrically attached to a ratemeter (Fig. 3) which measures the counts per minute for the part under test. The basic leakrate formula, based on Poiseuille flow, is used to calculate the leak rate for the device. The MSFC acceptance criterion is 1 mN/m^2-cc per second (1×10^{-8} atm-cc per sec). All relays that leak in excess of this amount are rejected.

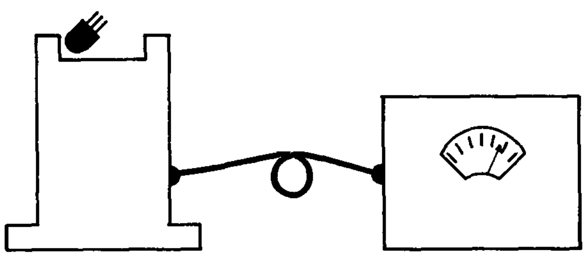


FIGURE 3. RADIFLO SYSTEM, COUNT PHASE

Experienced gained by using the Radiflo system for checking hermetic seals indicated that the results were frequently inconsistent with other hermetic-seal testing systems and Radiflo systems employed by industry. To obtain a better understanding of this inconsistency, MSFC awarded a contract to Mississippi State University in 1963 to investigate the irregularities in test data. As a result of this study, it was clearly shown that the basic concept using Poiseuille flow was not correct.

Molecular flow occurs at 1 mN/m^2-cc per second (10^{-8} atm-cc per sec) and is the leak-mode range which is of interest to MSFC. The difference between the Poiseuille flow and the molecular flow is due to the relationship between the size of the capillary diameter and the mean free path of the gas molecules involved. Poiseuille flow occurs when the diameter is considerably greater than the mean free path of the gas molecules. Molecular flow occurs when the diameter is considerably less than the mean free path of the gas molecules (Fig. 4).

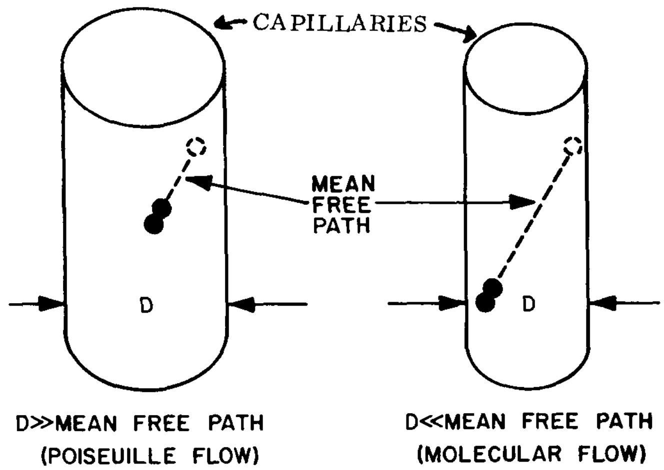


FIGURE 4. LEAK MODE

As shown in the following leak-rate equations, the pressure terms (in the denominators) are squared only in the Poiseuille equation:

Poiseuille: $\text{Leak Rate} = R/\,[KST(Pe^2 - Pi^2)]$

Molecular: $\text{Leak Rate} = R/\,[KST(Pe - Pi)]$

An alternate method used by manufacturers of electronic parts to verify hermetic seals is the helium mass spectrometer technique. Figure 5 illustrates the mass spectrometer device which employs a bell jar, a vacuum pump, and an electronic velocity filter. The hermetically sealed electronic component, which previously had been filled by the manufacturer with 5- to 10-percent helium, is placed under the bell jar and a vacuum is produced. After sufficient vacuum has been obtained, an electronic velocity filter is operated. This device deflects the helium ions, by means of a magnetic field, into a predetermined slot. As the helium ions are deflected, they produce a current which is amplified and electrically measured.

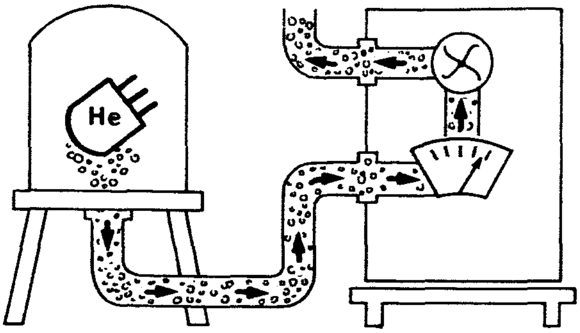


FIGURE 5. MASS SPECTROMETER HELIUM TRACER METHOD

Most vendors use the mass spectrometer for verifying hermetic seals, whereas MSFC uses the Radiflo system. The use of the two different systems results in conflicting and inconsistent test results. To resolve the problems of inconsistent test results, a mass spectrometer was obtained and used to test incoming parts. However, testing at this point did not reproduce the results obtained by the vendors employing the same technique. After an extensive study of this problem it was concluded that the use of the mass spectrometer could not effectively be employed in the MSFC acceptance testing. One reason is that the relays are filled with helium by the manufacturer, and there is no assurance that the helium is present within the part when it is checked at the receiving area. If the part leaked, tests using the mass spectrometer could not determine whether all the gas had leaked out before arrival or that none had leaked because of a good hermetic seal.

Most of the problems associated with Radiflo system have been solved and the system appears to be the optimum method for in-house verification of hermetic seals. There still are a few considerations which need attention; these are being investigated under a contract with Mississippi State University. The contract has two major objectives:

1) To find a correlation between the Radiflo and the mass spectrometer methods by envolving a factor that would correlate the two results and then specify a leak rate for the mass spectrometer method that would pass the Radiflo test.

2) To determine whether the present reject point of 1 mN/m^2-cc per second at a differential of 100 kN/m^2 (1 atmosphere) is adequate for extended space missions.

IV. SOLDERABILITY AND WELDABILITY VERIFICATION TECHNIQUES

One of the problems of electronic assembly inspection is the determination of whether a particular solder joint or weld module joint is a reliable connection.

This verification problem is exemplified by work such as soldering to a gold-plated printed circuit board. The gold combines with the solder and a gold/tin system results. The solder joint is discolored, and sometimes appears to be unsound due to porosity and discoloration. If the joint is welded instead of soldered, it is even more difficult to inspect visually. The answer to these problems would be to verify the solderability or weldability of electronic parts prior to the assembly operation at the receiving inspection level.

At times it appears that more concern is given to the electrical parameters of a device than to the compatibility of the lead material. Nevertheless, compatibility is essential: the lead material must be suitable to the soldering or welding operation required to connect the part to the next assembly, or an unacceptable assembly will result.

Contracts were awarded to the Martin-Marietta Corporation, Aerospace Division, and to the Lockheed Aircraft Corporation, Missile and Space Division, to establish standards of solderability and weldability of component lead materials and to provide an acceptable lead-material test for acceptance testing.

As a result of these contracts, a solderability test has been defined which closely simulates the production mode of flow soldering. The test, as shown in Figure 6, consists of several steps and the application of the solderability formula, $(KL_1 + L_2) / (D - d)$ = solderability rating. The first step is to bend the component lead around a 7.9 mm (5/16-inch) mandrel. The lead is then fluxed, dipped into molten solder, and finally submerged into a hot-oil bath. The lead is then removed, and after it has been cooled and cleaned, it is subjected to optical measurements and the dimensions, L_1, L_2, D and d, are obtained. In the formula shown, K is associated with L_1 as a weighing factor, L_1 is the inner length of the solder area, L_2 is the outside length of the solder area, D is the diameter of the solder area, and d is the diameter of the lead.

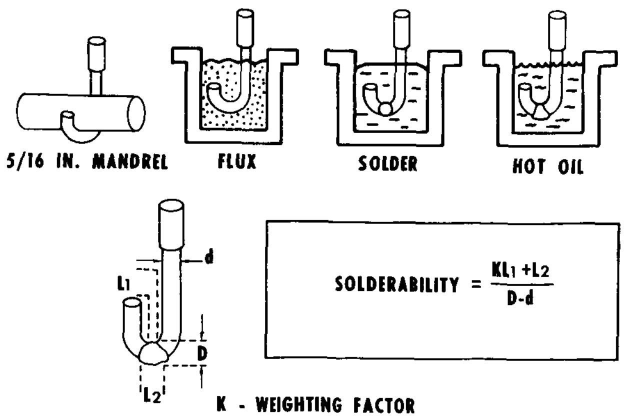


FIGURE 6. SOLDERABILITY TEST

The solderability-rating technique was employed for materials used in the fabrication of electronic assemblies to obtain the solderability test results shown in Figure 7.

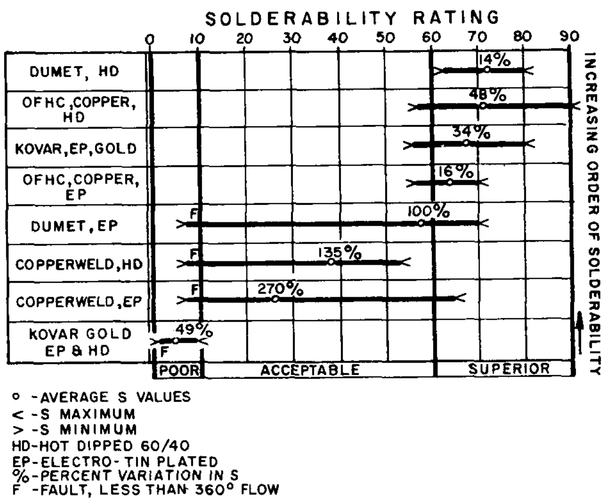
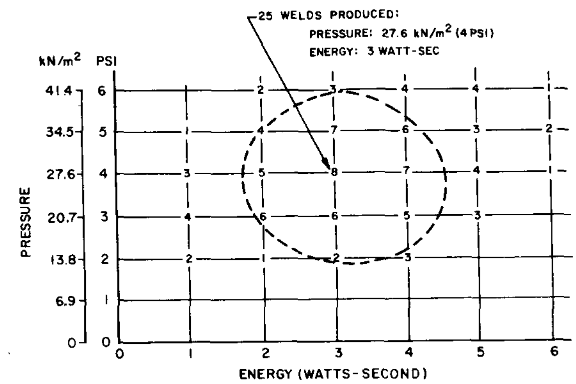


FIGURE 7. SOLDERABILITY TEST RESULTS

A similar analysis has been performed for welded modules. The welding test apparatus consists of a power supply with two electrodes. The component lead and interconnecting nickel ribbon are placed between the two electrodes and pressure is applied. The subsequent release of electrical energy welds the two materials.

To determine the quality of the weld produced, a pull test is employed which is essentially a tensile-shear force applied until the breaking strength of the weld is reached. By expanding this operation with variations of pressure and energy, a weld schedule is obtained. Figure 8 shows a weld-schedule chart with the weld pressure on the ordinate and the weld energy on the abscissa. When welds



$$\text{WELDABILITY RATING} = \frac{(\Delta\ \text{WATT-SEC})(\Delta\ \text{PRESSURE})(\text{MINIMUM PULL})}{(\%\ \text{VARIATION})(\text{AVERAGE BASE METAL STRENGTH})}$$

FIGURE 8. WELD SCHEDULE

are made with various pressures and energies, and this information is plotted on the chart, a weldability pattern is obtained. (The patterns will vary, depending upon the type and size of the material: some may be circular, others oblong.) The larger the area encompassed by this pattern, the better is the weldability of the material being tested. The optimum pressure/energy setting is determined from this weld schedule. In testing, 25 welds are produced from the optimum setting. The 25 welds are pull-tested and the results recorded. A weldability rating then is obtained from the weldability formula (Fig. 8) and the values obtained in the pull test.

This sequence has been used to obtain a weldability-rating chart, illustrated by Table III, which lists the basic parameters for weldability of the materials tested.

TABLE III. BASIC PARAMETERS FOR WELDABILITY RATING OF MATERIALS JOINED TO NICKEL "A" RIBBON

MATERIAL PLATING, SERIAL NO.	TYPE	Δ JOULES, (watt-sec)	Δ PRESSURE, Newtons (1bf)	VARIATION, Percent	MIN. PULL, Newtons (1bf)	AVG. TENSILE STRENGTH OF WEAKER MATERIAL	WELD-ABILITY RATING
BARE							
109	s.s. pins	5.25	62 (14)	15.6	72 (16.1)	20.54	3.7
114	Tantalum	3.29	53 (12)	14.1	68 (15.3)	20.54	2.2
107	Nickel "A"	4.17	45 (10)	17.8	67 (15.0)	19.8	1.8
108	Kulgrid 28	5.67	18 (4)	15.4	45 (10.1)	15.1	1.0
GOLD PLATED							
104	Dumet	3.83	27 (10)	11	73 (16.4)	20.54	2.8
112	Alloy 152	3.88	62 (14)	18.6	67 (15.1)	20.54	2.2
105	Kovar	2.86	53 (12)	17.9	69 (15.4)	20.54	1.4
111	Copperweld	4.00	45 (10)	20	28 (8.5)	13.1	1.3
113	Alloy 90	3.00	27 (6)	22.6	46 (10.4)	16.9	0.5
110	Alloy 180	2.33	18 (4)	116	15 (3.4)	18.9	0.014
TIN PLATED							
106	Cu OFHC	4.67	45 (10)	10.4	40 (9)	12.44	3.2
117	Nickel "A"	3.43	53 (12)	16.9	67 (15)	19.6	1.9
118	Dumet	4.00	53 (12)	23.5	67 (15.1)	20.54	1.5
119	Kovar	2.63	62 (14)	21.1	63 (14.2)	20.54	1.2

It is believed that with the development of these two major techniques, the determination of solderability or weldability will be simplified.

V. METALLIC COATING TECHNIQUES FOR MAINTAINING SOLDERABILITY

Recent laboratory tests and hardware evaluations have shown that present industrial techniques for silver-plating copper conductors are inadequate for preventing Red Plague. Copper is exposed to the atmosphere because of imperfections in the silver plating; in the presence of moisture and oxygen, a galvanic couple between the silver and copper is produced which eventually reduces the wire to powder.

Since this type of corrosion recently appeared on the guidance and control platform being produced by Bendix Corporation, an agreement was made to change from silver-plated wire to nickel-plated wire for work under this contract.

Various wire manufacturers are studying the silver-plating problems in an effort to improve the plating techniques. In addition, studies are under way to determine whether an underlay of nickel will prevent the Red Plague.

VI. INFRARED TESTING OF ELECTRONIC PARTS

Infrared testing of electronic parts will detect incipient failures that are not normally discovered by routine electrical functional testing. The objective of this new testing technique is to complement the electrical functional testing by scanning the electronic part during the functional test to determine the amount of infrared radiation emanating from the part under test.

In 1964, a procurement specification was written for obtaining an infrared test station to be installed by Boeing Company. The equipment (Figs. 9 and 10) was fabricated, and has been in operation

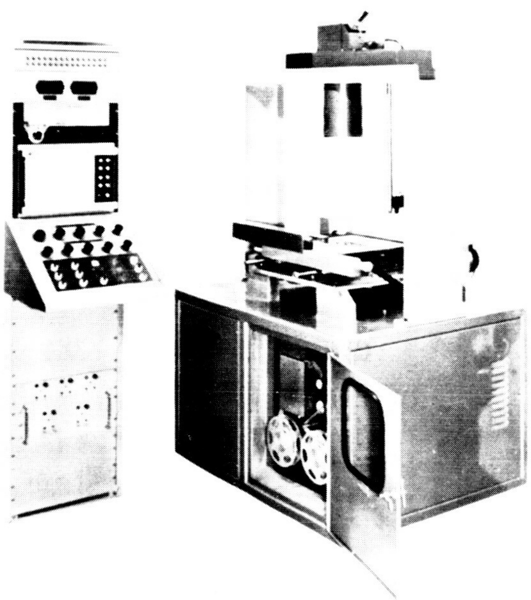


FIGURE 9. INFRARED TEST STATION

since September 1964. Current operations are aimed toward establishing a normal pattern for selected hardware configurations. Once a normal pattern is obtained for a device, subsequent testing can determine how far others deviate from the norm. With this information, the projected operating life of a particular device under test can be obtained.

One problem encountered is the variable emissivity of component surfaces, resulting from changes made by the vendor in the pigment or other characteristics of the paint or other protective coatings used on the devices. Because of the different surface-emissivity ratings, the infrared-radiation readout must be modified for each variable.

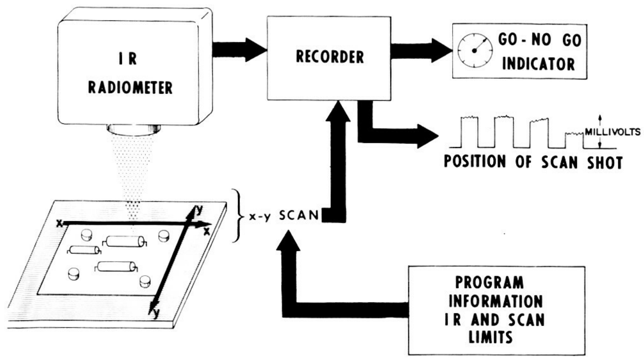


FIGURE 10. OPERATIONAL SEQUENCE OF INFRARED TEST STATION

The Martin Marietta Corporation, Aerospace Division, has a contract to develop a constant-emissivity coating that can be used on all components, thus making infrared measurements independent of the various coatings used on the devices. As shown in Figures 11 and 12, this test station provides a thermal profile of components placed on the X-Y table and in the operating mode.

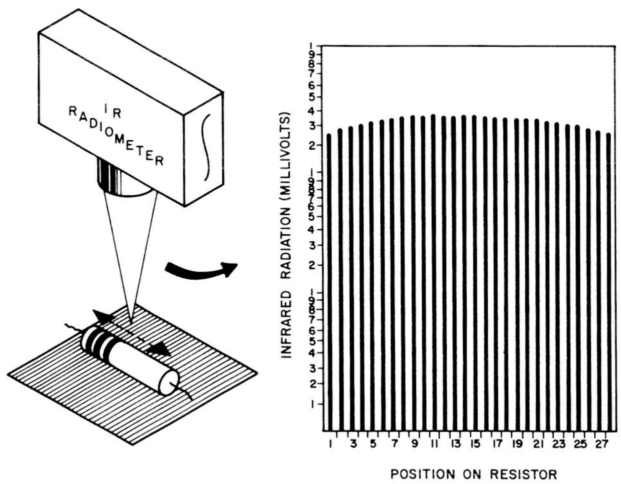


FIGURE 11. THERMAL PROFILE (END TO END) OF A CARBON COMPOSITION RESISTOR

It is too early to say that the infrared-radiation detection and recording system, currently under evaluation, will complement the present reliability program. However, the test results are encouraging, and if the development of an emissivity coating to solve the surface variance problem is successful, then this system should provide a method of predicting the successful operating life of electronic parts and subassemblies.

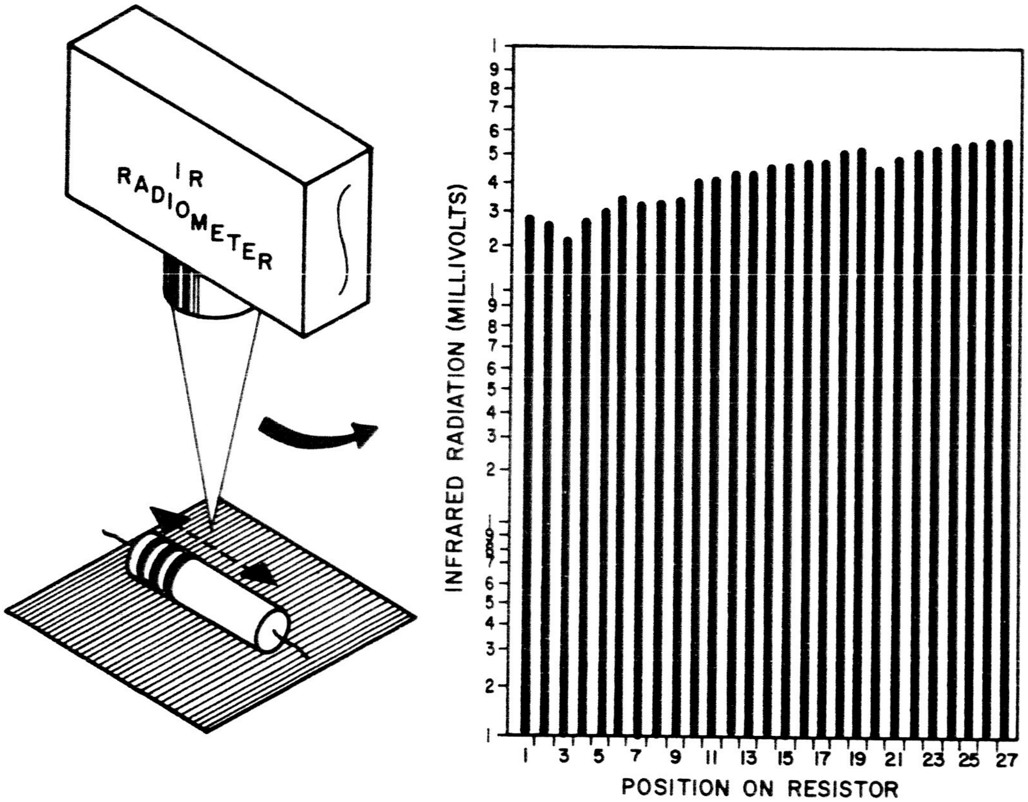


FIGURE 12. THERMAL PROFILE (END TO END) OF A WIRE-WOUND RESISTOR

APPROVAL

RESEARCH ACHIEVEMENTS REVIEW SERIES NO. 10

By R. L. Smith, Jr., M. J. Berkebile and R. W. Neuschaefer

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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